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T. Shiyan, Z. Cuiquan, and Y. Zhuojia

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BOUNDARY LAYER STRUCTURAL ANALYSIS OF LARGE SCALE PRECIPITATION AT WEATHER FRONT

Tao Shiyan, Zhu Cuiquan, and Ye Zhuojia
Institute of Atmospheric Physics, Chinese Academy of Sciences
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Since a long time ago, precipitation forecasting has been a difficult problem. One of the main reasons is possibly that the median scale triggering regime of precipitation has not been sufficiently explained [1]. This paper utilizes the observation data at the 325-meter meteorological tower at the Institute of Atmospheric Physics of the Chinese Academy of Sciences, sounding data of acoustic radar, and conventional data to analyze the triggering regime of two heavy precipitations in the Beijing area from 0230 to 0430 hours on 27 August 1980.

The time segment for taking wind and temperature data was 20 seconds; the time segment for taking vertical velocity data was 5 seconds; and the time segment for taking the relative humidity data was 10 seconds. Joint observations were made using the acoustic radar.

I. Weather Situation and Precipitation Process

At 2300 hours on 26 August 1980, a cold front moved over Beijing. Before the passage of the front, there was cold cloudy weather at Beijing; about two hours following the front passage, heavy precipitation occurred at this station. Two heavy rains occurred from 0230 to 0430 hours on the 27th, the first rain lasted from 0232 to 0254 hours with precipitation of 5 millimeters; the second rain lasted from 0350 to 0430 hours with precipitation of 11 millimeters. The rain intensity rapidly decreased after 0430 hours. Drizzle kept on until noon of the 27th.

II. Characteristics of Meteorological Element Field and Acoustic Echo

As revealed by the continuous gradient of temperature difference in the tower layer, after 1800 hours on the 26th, there was a layer of temperature inversion near the 30-meter altitude in the lower levels of the meteorological tower. This near-ground shallow layer of temperature inversion is radiation inversion, which was maintained throughout the night. At 2120 hours on the 26th, a second temperature inversion layer occurred at altitude of 180 meters near the tower; the inversion was relatively weak at the beginning, but gradually intensified and thickened. The altitude of the temperature inversion bottom was lowered; at about 0010 hours on the 27th, the bottom of the inversion layer reached the lowest point, an altitude of about 60 meters (Fig. 1). At 0035 hours, the second temperature inversion layer disappeared. From 1200 hours on the 26th to 0035 hours on the 27th, a consistent southwesterly was observed at the station. From 0036 to 0056 hours, the wind direction was shifted from southwesterly to westerly, and then turning to northwesterly. In this period, the weather front passed the station. Before 0035 hours, the meteorological station was in the southwestern current ahead of the front line. Therefore, the second inversion layer before 0035 hours was related to the ascending motion of the local airmass ahead of the rapidly developing cold front before its passage. When the front zone passed the station area, the inversion zone was interrupted. The time this inversion layer was maintained was about three hours. Beginning from 0103 hours on the 27th, the second inversion layer (at the upper portion of the tower layer) began to be established. The inversion layer was sometimes intense, sometimes weak, and sometimes just interrupted. Following appearance of the temperature inversion layer, its altitude gradually lowered, generally remaining in the vicinity of the 250-meter altitude. We can see from wind-field analysis that the re-establishment of the second inversion layer occurred during the situation of the heavier northwesterly. At that time, the front line had already passed the area and the wind direction in the tower layers slightly turned to the northward. With the terrain effect of the Yanshan Mountains, at night the mountain wind was consistent in the direction of the large scale winds, blowing from the northwest toward the southeast plain area. A clear density flow (Fig. 2) appeared in the lower layer; this density flow is relatively thin. The height of the head of the density flow was in the vicinity of the tower top. The cold center was in the vicinity of 40 to 60 meters in altitude. From 0105 to 0300 hours on the 27th, turbulence of a third density flow appeared in the lower level of the tower. The re-establishment of the second temperature inversion layer was related to the advancing of this density flow.

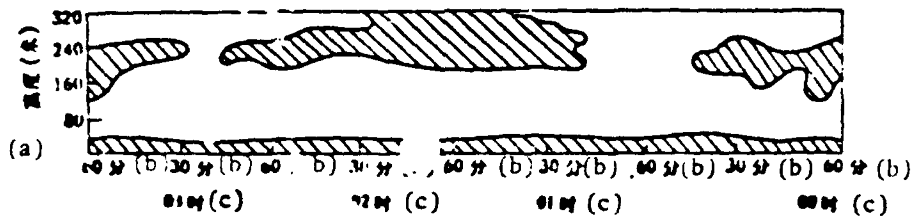

Fig. 1. Time-space distribution of temperature difference from 0001 to 0400 (0360) hours on 27 August 1980: a temperature inversion layer appeared in the zone of slanted lines.
Key: (a) Altitude (meters); (b) Minutes; (c) Hours.

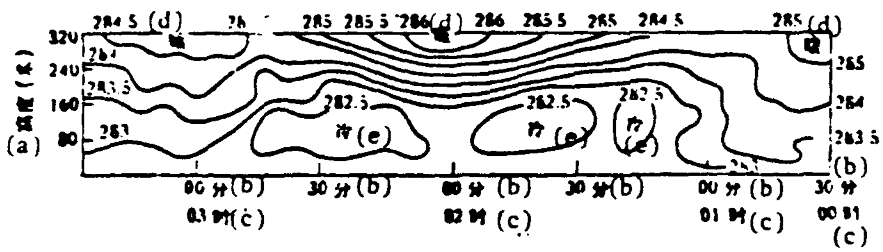

Fig. 2. Time-space distribution of θ values from 0030 to 0330 hours on 27 August 1980.
Key: (a) Altitude (meters); (b) Minutes; (c) Hours; (d) Warm; (e) Cold.

As revealed by the measured wind data (diagram not included) in the tower layers, the southwesterly ahead of the front occurred before 0035 hours; the wind force was greater, attaining 10 meters per second at the top of the tower layers. After the weather front passed, the wind direction turned to northwesterly with smaller force. However, beginning from 0120 hours, the easterly was slightly deviated at an altitude of 180 meters; later, its thickness gradually increased. At 0150 hours, the slightly deviated easterly was in a layer about 60 meters thick from 140- to 200-meter altitude; the wind direction also gradually turned from north-north-east to easterly. After 0235 hours, it turned to southeasterly. This revealed that during the period there was the passage of turbulence; its altitude was basically consistent with the altitude of the second inversion layer. The time the turbulence occurred was behind that of establishing the second inversion layer by 20 minutes. This wavy motion occurring above the second temperature inversion layer was very closely related to the precipitation. Thirty minutes after the appearance of the slightly deviated easterly at 180 meters (at 0150 hours), drizzle began. Following intensifying turbulence of the easterly, its thickness rapidly increased to 80 to 90 meters. At 0230 hours, the first heavy precipitation occurred. This wavy motion above the second inversion layer was possibly closely related to the precipitation process.

The properties of the echo wave of the acoustic radar in this precipitation process were as follows: by 2110 hours on the 26th, there appeared echo waves of weak temperature inversion at an altitude of a little over 300 meters. After 2120 hours, this layer of the echo wave appeared very clear with slightly lowering of altitude. About the altitude of 250 meters, the echo wave connected to the echo waves of radiation temperature inversion of the low layers, becoming a deep, thick echo wave zone. The time and altitude (of its position) of the occurrence of the echo wave matched with the temperature inversion obtained through analysis of temperature difference at the meteorological tower. By 0030 hours on the 27th, the echo waves of temperature inversion had an abrupt variation. Intense variation occurred in echo waves of the high layers; this was at the time of the passing weather front. Clearly, this vibration of temperature inversion echo waves was related to the turbulence of the density flow when the weather front passed. After 0200 hours, the vibration waveform of the echo waves of the second temperature inversion layer was very clear, with the altitude of the wavy motion in the vicinity of the 250-meter level; the period of the wavy motion was about 8 to 9 minutes, and the vibration amplitude was about 200 meters. With the appearance of this wavy motion, at 0232 hours heavy precipitation occurred. From 0230 to 0256 hours, precipitation echo waves occurred. This phenomenon demonstrated that the heavy precipitation was related to the vibration of the second temperature inversion layer in the vicinity of 250-meter altitude. The propagation of wavy motion in the temperature inversion layer is a type of gravity internal wave.

We analyzed [2] the distribution properties of vertical velocities within the lower boundary layer during intense weather conditions; it was discovered that vertical velocities appeared in the form of intense pulses with maximum values possibly attaining (positive or negative) several meters per second. However, during the precipitation process upon passage of a large scale weather front (Fig. 3), it was the ascending motion in the warm zone ahead of the weather front with maximum value possibly at 80 to 90 cm/sec. After the weather front passed, until the beginning of precipitation, basically it was the ascending motion with magnitude of tens of centimeters per second. At the bottom of the tower layers, there was a zone of shallow descending motion. From 0230 to 0300 (0260) hours on the 27th during the period of heavy precipitation, the vertical motions of the wind were relatively complex, appearing as alternations of ascending and descending motions with magnitudes at 40 to 50 centimeters per second. It is worth special attention that after the first heavy rain, intense ascending motions (40 to 60 centimeters per second) were consistently maintained. Later at 0350 hours, heavy precipitation again occurred. However, the situation was different during the second heavy rain; after beginning of the precipitation, descending motion (or weak ascending motion of only several centimeters per second) occurred in the tower layers. For a considerable period of time following the heavy precipitation, the vertical motion was almost zero and the precipitation process was thus concluded. Therefore, within a certain degree, we can refer to vertical motion to estimate whether or not the possibility exists of an intense precipitation closely following a heavy precipitation.

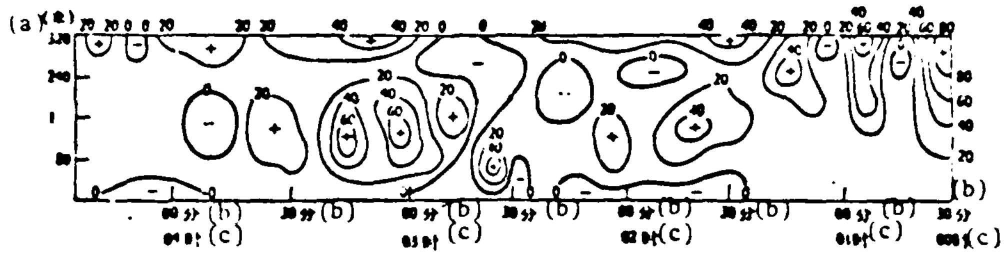

Fig. 3. Time-space distribution of vertical velocity from 0030 to 0430 hours on 27 August 1980.
Key: (a) Meters; (b) Minutes; (c) Hours.

Spectral analyses were made of temperatures, horizontal wind speeds and vertical velocities. In spectra of temperature and horizontal wind speed, excluding that in the vicinity of 50 to 60 minutes, the low-frequency spectrum has relatively high energy; there was another relatively high energy peak zone in the vicinity of 8 minutes. In addition, from the 180-meter altitude to the tower top, the distribution rule is basically consistent. Figure 4 shows a distribution curve of the temperature energy spectrum at a 240-meter altitude; a medium scale system with period about 8 minutes played a very important role in this precipitation process. In the spectral analysis of vertical velocities, the wavy motion with period between two to three minutes has relatively high energy. In other words, the high-frequency spectra are more important in vertical motions.

III. Preliminary Conclusions

By analyzing the continuous observation data through sounding of the boundary layer, it was discovered that the heavy precipitation process of the large scale front precipitation is triggered by a medium scale system. In this process, the medium scale system with period about 8 to 9 minutes was the main one.

This wavy motion occurred at night, caused by shallow density flow at low layers; this is a gravity internal wave.

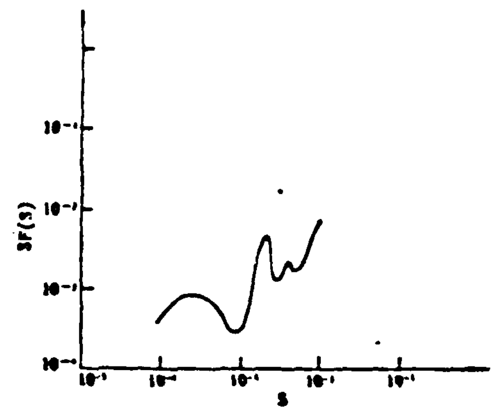

Fig. 4. Time-space distribution of vertical velocities from 0030 to 0430 hours on 27 August 1980.
Key: (a) Meters; (b) Minutes; (c) Hours.

The wavy motion has a clear reaction during wind observation by a single weather station. Since the density flow is propagated at medium altitude of the tower layers, the inhomogeneous vertical distribution of wind speed in the tower layer produces a clear tangential shift. The reaction of this wavy motion to the time variation of the wind is the easterly disturbance.

From echo waves of temperature inversion using acoustic radar and wind analyses, it was proved that the altitude of the appearing wavy motion is in the vicinity of 250 meters.

In the Beijing area when the weather front passed at night, consideration should be given to the superposition of mountain wind and slightly deviated northerly air flow; this superposition will intensify the density flow at low layers following the front and will cause the establishment of the second temperature inversion layer and stimulate the inversion layer to produce the gravity waves. Therefore, for night passage of weather front, consideration should be given to this amplitude increase function [3].

LITERATURE

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3. Tao Shiyan et al., ZHONGGUO ZHI BAOYU [Rainstorms in China], Science Publishing House, 1980.